Effect of contralateral severe stenosis or carotid occlusion on duplex criteria of ipsilateral stenoses: Comparative study of various duplex parameters

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Purpose: This study compares the accuracy of various duplex parameters in grading ipsilateral carotid stenoses in patients with contralateral severe stenoses or occlusion.
Methods: Four duplex criteria were correlated to arteriography in 356 carotid arteries in blind fashion: (1) standard criteria: a peak systolic frequency (PSF) of the internal carotid artery (ICA) of ≥4 kHz was used to diagnose ≥50% stenosis; (2) new criteria: a PSF of the ICA of ≥4.5 kHz was used; (3) Fujitani criteria: a PSF of the ICA of >4.5 kHz and an end-diastolic frequency of <5.0 kHz was used; (4) internal carotid/common carotid artery (ICA/CCA) PSF ratio of ≥1.5 was used.
Results: The standard method overestimated 56 (16%) of 356 stenoses in contrast to 3% for the new method ($p < 0.001$), and this effect was most evident in the 50% to <80% stenosis category (30%). The Fujitani method underestimated 97 (27%) of 356 stenoses, and the ICA/CCA ratio overestimated stenoses in 77 (22%) of 356. The overall exact correlation was 94%, 82%, 70%, and 75% for the new, standard, Fujitani, and ICA/CCA ratio, respectively. The κ statistic and corresponding confidence intervals for the new method (κ = 0.923, ±0.016) are significantly higher ($p < 0.001$) than those for the standard method (κ = 0.760, ±0.027), the Fujitani method (κ = 0.608, ±0.031), and the ICA/CCA ratio method (κ = 0.642, ±0.051). The overall accuracy in diagnosing ≥50% ipsilateral stenosis in the whole series was 85% for the standard method, 97% for the new method, 95% for the Fujitani method, and 81% for the ICA/CCA ratio. The new method was superior to the standard and ICA/CCA ratio methods ($p < 0.001$) and the Fujitani method ($p = 0.024$).
Conclusions: The presence of significant contralateral stenosis (≥50%) can lead to overestimation of ipsilateral stenosis if the standard criteria are used; however, this problem can be avoided by using a PSF of the ICA of ≥4.5 kHz for the diagnosis of ≥50% stenosis. (J VASC SURG 1995;22:751-62.)

Duplex ultrasonography, in which real-time imaging is combined with Doppler spectral analysis, has become the preferred method for noninvasive evaluation of extracranial carotid arterial disease. Assessment of the degree of internal carotid stenosis is based largely on peak systolic and end-diastolic frequency (or velocity) criteria.[1-8]

A number of studies in the recent literature, however, have reported decreased accuracy of duplex scanning in predicting the degree of ipsilateral internal carotid stenosis in the presence of contralateral high-grade stenosis or carotid occlusion.[1-5] When conventional standard criteria[6] were applied in this circumstance, the result was an overestimation of the degree of ipsilateral stenosis (up to 48%),[5] often resulting in incorrect assignment to a higher category of disease and thus creating a false-positive interpretation.[1-5] It has been proposed that this phenomenon occurs because of a compensatory increase in

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Table I. Doppler frequency spectral or velocity criteria for carotid artery stenosis

Classification	*Arteriographic lesion*	*Spectral criteria*
Standard method*		
Grade I	1%-15% Diameter reduction	PSF <4 kHz (<125 cm/sec), minimal SB
Grade II	16%-49% Diameter reduction	PSF <4 kHz (<125 cm/sec), increased SB
Grade III	50%-79% Diameter reduction	PSF ≥4 kHz (≥125 cm/sec) EDF <4.5 kHz (<140 cm/sec)
Grade IV	80%-99% Diameter reduction	PSF >4 kHz (>125 cm/sec) EDF >4.5 kHz (>140 cm/sec)
Grade V	Occlusion	No internal carotid flow signal Low or reversed diastolic component in common carotid artery
New method-similar to standard method except for the following		
Grade II	16%-49% Diameter reduction	PSF <4.5 kHz (<140 cm/sec) EDF <4.5 kHz (<140 cm/sec)
Grade III	50%-79% Diameter reduction	PSF ≥4.5 kHz (≥140 cm/sec) EDF <4.5 kHz (<140 cm/sec)
Grade IV	80%-99% Diameter reduction	PSF >4.5 kHz (>140 cm/sec) EDF >4.5 kHz (>140 cm/sec)
Fujitani method-same as standard method except for the following		
Grade II	16%-49% Diameter reduction	PSF >4 kHz (>125 cm/sec) EDF <5 kHz (<155 cm/sec)
Grade III	50%-79% Diameter reduction	PSF >4.5 kHz (>140 cm/sec) EDF <5 kHz (<155 cm/sec)
Grade IV	80%-99% Diameter reduction	PSF >4.5 kHz (>140 cm/sec) EDF >5 kHz (>155 cm/sec)
ICA/CCA ratio method		
Grade I & II	1%-49% Diameter reduction	SVR <1.5
Grade III	50%-79% Diameter reduction	SVR ≥1.5, PEDV <100 cm/sec
Grade IV	80%-99% Diameter reduction	SVR ≥1.8, PEDV >100 cm/sec
Grade V	Occlusion	No internal carotid artery flow signal

*Modified from Zierler RE, Strandness DE Jr. In: Wood JH, editor. Cerebral blood flow physiologic and clinical aspects. New York, McGraw-Hill, 1987:311-23.
PSF, Peak systolic frequency; *EDF*, end-diastolic frequency; *SB*, spectral broadening; *SVR*, systolic velocity ratio (ICA/CCA peak systolic velocity ratio); *PEDV*, peak end-diastolic velocity.

flow velocity in the ipsilateral carotid system to maintain a stable cerebral circulation via the Circle of Willis.[2]

Fujitani et al.[5] were the first to recommend modification of the standard duplex criteria in patients with contralateral internal carotid occlusion. However, in his study only the effect of the contralateral total carotid occlusion was studied. Patients with less than total occlusion of the contralateral artery were excluded from the study population.

The recognition of this phenomenon as consistent and clinically significant led us to undertake a retrospective study to compare the accuracy of various existing duplex criteria (standard,[6] Fujitani,[5] internal carotid/common carotid (ICA/CCA) ratio[7]) used in grading ipsilateral carotid stenosis in patients with contralateral high-grade stenosis or occlusion. In addition, we propose a new modified duplex criteria that we believe to be superior to the existing criteria in terms of overall accuracy.

These new criteria were developed because of our dissatisfaction with the results of the standard method in grading ipsilateral stenosis in the presence of severe contralateral disease. We had observed that most patients with ≥50% stenosis on arteriography had a peak systolic frequency of the internal carotid artery of ≥4.5 kHz in the presence of severe contralateral disease. This finding led us to apply this new cutoff Doppler criteria on 12 patients who had both duplex ultrasonography and arteriography. All of these patients except one had comparable grades on arteriography. The new criteria were applied prospectively to this study population.

PATIENT POPULATION AND METHODS

From January 1992 to December 1993, 178 patients (356 arteries) were identified as having significant (>50%) internal carotid artery stenosis by carotid duplex ultrasonography, and they subsequently underwent carotid arteriography within 6 weeks.

In each patient carotid color duplex ultrasonog-

Table II. Comparison of duplex grades to arteriogram grades

	Arteriogram grades					
Duplex grades	*Grade I (%)*	*Grade II (%)*	*Grade III (%)*	*Grade IV (%)*	*Grade V (%)*	*Total*
Standard method						
Grade I	38 (100)	0	0	0	0	38
Grade II	0	17 (100)	0	0	0	17
Grade III	2 (1)	52 (30)	111 (64)	8 (5)	0	173
Grade IV	0	0	0	87 (100)	0	87
Grade V	0	0	0	2 (5)	39 (95)	41
(κ = 0.760, 95% confidence interval = 0.708-0.812)						
New method						
Grade I	38 (100)	0	0	0	0	38
Grade II	2 (3)	63 (93)	3 (4)	0	0	68
Grade III	0	6 (5)	108 (88)	8 (7)	0	122
Grade IV	0	0	0	87 (100)	0	87
Grade V	0	0	0	2 (5)	39 (95)	41
(κ = 0.923, 95% confidence interval = 0.891-0.955, $p < 0.001$)						
Fujitani method						
Grade I	38 (64)	20 (34)	1 (2)	0	0	59
Grade II	2 (4)	43 (78)	9 (16)	1 (2)	0	55
Grade III	0	6 (4)	101 (58)	66 (38)	0	173
Grade IV	0	0	0	28 (100)	0	28
Grade V	0	0	0	2 (5)	39 (95)	41
(κ = 0.608, 95% confidence interval = 0.547-0.668)						
ICA/CCA ratio method						
Grades I and II	27 (48)	21 (38)	4 (7)	1 (2)	3 (5)	56
Grade III	13 (8)	48 (30)	93 (58)	7 (4)	0	161
Grade IV	0	0	14 (14)	87 (86)	0	101
Grade V	0	0	0	2 (5)	36 (95)	38
Total	40	69	111	97	39	356
(κ = 0.642, 95% confidence interval = 0.542-0.742)						

raphy was performed by an experienced vascular technician with high-resolution real-time imaging (7.5 Mhz) and pulsed Doppler (5.0 Mhz) digital fast Fourier spectrum analysis (Ultramark-9, HDI system, Advanced Technology Laboratories, Bothel, Wash.). Standard duplex techniques included real-time imaging of the vessels in sagittal and transverse planes and multiple Doppler frequency and velocity measurements along the course of the vessel. The Doppler angle of incidence was maintained at 60 degrees. Peak systolic and end-diastolic frequencies and velocities were recorded in the common, internal, and external carotid arteries. Specific recordings were also taken proximal to the stenosis, at the stenosis site, and immediately distal to the stenosis in the internal carotid artery as seen by the real-time imaging. All duplex scans were then interpreted by a single investigator blinded to the arteriographic findings.

Criteria for duplex ultrasonography classification of the degree of stenosis are shown in Table I. Four different sets of criteria for each patient were analyzed: (1) the standard criteria (University of Washington),[6] (2) Fujitani criteria,[5] (3) ICA/CCA ratio criteria,[7] and (4) the new revised criteria that we are proposing. These criteria were used to assign each artery to one of five categories: grade I, 1% to 15% stenosis; grade II, 16% to 49% stenosis; grade III, 50% to 79% stenosis; grade IV, 80% to 99% stenosis; and grade V, total occlusion.

Arteriographic evaluation was performed with selective intraarterial digital subtraction, four-vessel arch aortography, and carotid arteriography. In each patient the point of maximal stenosis was measured and then divided by the diameter of the normal distal internal carotid artery to calculate the percent of stenosis (diameter reduction). All arteriograms were reviewed by two investigators blinded to the duplex findings. If a significant discrepancy was noted between the two investigators' interpretations, an additional third investigator reviewed the arteriogram separately to provide a consensus. The degree of stenosis was estimated to the closest whole percentage. Each internal carotid artery stenosis was then classified into one of five categories similar to the duplex categories.

Table III, A. Effect of grade I contralateral stenosis on duplex grades of ipsilateral stenosis

Ipsilateral stenosis duplex grades	*Arteriogram grades*			
	Grade III	*Grade IV*	*Grade V*	*Total*
Standard method*				
Grade III†	18	0	0	18
Grade IV	0	19	0	19
Grade V	0	0	3	3
New method‡				
Grade III	18	0	0	18
Grade IV	0	19	0	19
Grade V	0	0	3	3
Fujitani method§				
Grade III	18	14	0	32
Grade IV	0	5	0	5
Grade V	0	0	3	3
ICA/CCA ratio method‖				
Grade III	15	0	0	15
Grade IV	3	19	0	22
Grade V	0	0	3	3

*Kappa = 1.0; kappa ± SD = 1.0.
†No patients in our series with grade I contralateral stenosis had grade I or II stenosis of the ipsilateral side.
‡Kappa = 1.0, kappa ± SD = 1.0.
§Kappa = 0.391; 95% CI = 0 to 1.0; kappa ± SD = 0.391 ± 0.379.
‖Kappa = 0.867; 95% CI = 0.426 to 1.0; kappa ± SD = 0.867 ± 0.225.

STATISTICAL METHODS

The κ statistic was used as a measure of correlation between duplex grades and arteriography. A κ of 1.0 indicates perfect agreement, whereas a κ of 0.0 indicates an agreement by chance. Ninety-five percent confidence intervals of κ statistics were calculated for comparison between the different methods. Nonoverlapped confidence intervals indicate a significant difference.

The sensitivity, specificity, positive predictive value, negative predictive value, and overall accuracy values were also calculated for various methods in diagnosing ≥50% ipsilateral stenosis in the presence of severe contralateral stenosis or occlusion. These values were compared with the use of the Z score statistic for proportions of vessels with the "correct" designations.

RESULTS

The study population included 178 patients (356 arteries) with an age range of 39 to 86 years (mean 68 years). A total of 103 men and 75 women were included. The indications for color duplex ultrasonography included hemispheric transient ischemic attacks in 49 (28%) patients, hemispheric cerebrovascular accidents in 24 (13%) patients, and asymptomatic carotid bruit with or without nonhemispheric transient ischemic attack symptoms in 105 (59%) patients. Unilateral significant internal carotid artery stenosis (≥50% stenosis) or occlusion by arteriography was found in 247 arteries (97 had ≥80% to 99% stenoses, and 39 had total occlusion).

Table II compares the results of duplex grades with those of arteriography on the basis of four different criteria. The standard method overestimated 52 (30%) of 173 carotid stenoses from grade II to grade III. Similarly, the ICA/CCA ratio method overestimated 48 (30%) of 161 carotid stenoses from grade II to grade III. However, the Fujitani method underestimated 66 (38%) of 173 stenoses from grade IV to grade III. When the new criteria were used, only 6 (5%) of 122 stenoses were overestimated from grade II to grade III. The exact correlation between duplex grades and arteriography was best with the new criteria (94%) in contrast to 82% for the standard method, 70% for the Fujitani method, and 75% for the ICA/CCA ratio method. The overall overestimation of the disease was 16% for the standard method and 22% for the ICA/CCA ratio method but only 3% for the new and Fujitani methods. The overall underestimation of the disease was 2% for the standard method, 3% for the new method, 27% for the Fujitani method, and 4% for the ICA/CCA ratio method.

The κ statistic and corresponding confidence intervals for the new method (κ = 0.923, ±0.016) were significantly higher ($p < 0.001$) than those of the standard method (κ = 0.760, ±0.027), the Fujitani method (κ = 0.608, ±0.031), and the ICA/CCA ratio method (κ = 0.642, ±0.051).

Table III, B. Effect of grade II contralateral stenosis on duplex grades of ipsilateral stenosis

Ipsilateral stenosis duplex grades	*Arteriogram grades*				
	Grade II	*Grade III*	*Grade IV*	*Grade V*	*Total*
Standard method*					
Grade III	2	25	3	0	30
Grade IV	0	0	26	0	26
Grade V	0	0	1	12	13
New method†					
Grade II	1	0	0	0	1
Grade III	1	25	3	0	29
Grade IV	0	0	26	0	26
Grade V	0	0	1	12	13
Fujitani method‡					
Grade II	1	2	0	0	3
Grade III	1	23	18	0	42
Grade IV	0	0	11	0	11
Grade V	0	0	1	12	13
ICA/CCA ratio method§					
Grade III	2	20	3	0	25
Grade IV	0	5	26	0	31
Grade V	0	0	1	12	13

*Kappa = 0.865; 95% CI = 0.572 to 1.0; kappa ± SD = 0.865 ± 0.150.
†Kappa = 0.889; 95% CI = 0.582 to 1.0; kappa ± SD = 0.889 ± 0.154.
‡Kappa = 0.528; 95% CI = 0.259 to 0.798; kappa ± SD = 0.528 ± 0.137.
§Kappa = 0.751; 95% CI = 0.490 to 1.0; kappa ± SD = 0.751 ± 0.133.

Effect of contralateral stenosis by grades on the degree of ipsilateral stenosis.

Tables IIIA to IIIE summarize the effect of contralateral stenosis, grades I through V, as demonstrated by arteriography on the degree of ipsilateral stenosis by various Doppler criteria. No effect was seen when the contralateral stenosis was less than 50% (grades I and II stenoses) regardless of which criteria were applied. When the contralateral stenosis was ≥50% (grades III, IV, and V stenoses), however, the new criteria proved superior. When the effects of grade III contralateral stenosis were analyzed, 19 of 56 grade III ipsilateral stenoses by duplex technique with the standard method were grade II stenoses by arteriography in contrast to only one out of 36 stenoses for the new method. Once the contralateral stenosis reaches ≥80% (grade IV), the effect becomes much more pronounced. Twenty-one of 45 grade III ipsilateral stenoses by duplex technique with the standard method were grade II stenoses by arteriography in contrast to only four of 26 stenoses with the new method. Similar observations were noted when other Doppler criteria were used. As noticed in Table III, the κ value for the new method ($\kappa = 0.919 \pm 0.030$) was significantly higher ($p < 0.001$) than that of the other methods for patients with grade III contralateral stenosis. Similarly, the new method was superior to the other methods in patients with grades IV and V contralateral stenoses.

Effect of significant contralateral stenosis on the diagnosis of equal to or >50% ipsilateral stenosis: Effect of 50% to <80% contralateral stenosis

Although the sensitivity in predicting ≥50% ipsilateral stenosis with the standard method was 100%, the specificity was only 56% with a positive predictive value of 78%. This result was in contrast to the new method in which the sensitivity was 97%, the specificity was 98%, and the positive predictive value was 99% (Table IV). Similar poor specificity and lower positive predictive values were noted when the ICA/CCA ratio method was used. The Fujitani method had comparable results to the new method. The overall accuracy of the new method was statistically superior to that of the standard and ICA/CCA ratio methods ($p < 0.001$).

Effect of 80% to 99% contralateral stenosis

As noticed in Table V, the sensitivity in predicting ≥50% ipsilateral stenosis in this group of patients with the standard method was 100%; however, the specificity was only 53% with a positive predictive value of 68% and an overall accuracy of 76%. This result was in contrast to the new method in which the

Table III, C. Effect of grade III contralateral stenosis on duplex grades of ipsilateral stenosis

Ipsilateral stenosis duplex grades	*Arteriogram grades*					
	Grade I	*Grade II*	*Grade III*	*Grade IV*	*Grade V*	*Total*
Standard method*						
Grade I	18	0	0	0	0	18
Grade II	0	6	0	0	0	6
Grade III	0	19	34	3	0	56
Grade IV	0	0	0	16	0	16
Grade V	0	0	0	1	14	15
New method†						
Grade I	18	0	0	0	0	18
Grade II	0	24	2	0	0	26
Grade III	0	1	32	3	0	36
Grade IV	0	0	0	16	0	16
Grade V	0	0	0	1	14	15
Fujitani method‡						
Grade I	18	8	1	0	0	27
Grade II	0	16	2	1	0	19
Grade III	0	1	31	12	0	44
Grade IV	0	0	0	6	0	6
Grade V	0	0	0	1	14	15
ICA/CCA method§						
Grade II	13	6	2	1	0	22
Grade III	5	19	29	2	0	56
Grade IV	0	0	3	16	0	19
Grade V	0	0	0	1	14	15

*Kappa = 0.729; 95% CI = 0.632 to 0.825; kappa ± SD = 0.729 ± 0.049.
†Kappa = 0.919; 95% CI = 0.861 to 0.977; kappa ± SD = 0.919 ± 0.030.
‡Kappa = 0.697; 95% CI = 0.598 to 0.797; kappa ± SD = 0.697 ± 0.051.
§Kappa = 0.589; 95% CI = 0.403 to 0.775; kappa ± SD = 0.589 ± 0.095.
Kappa statistics for the new method are significantly higher ($p < 0.001$) than those for any other method.

Table III, D. Effect of grade IV contralateral stenosis on duplex grades of ipsilateral stenosis

Ipsilateral stenosis duplex grades	*Arteriogram grades*					
	Grade I	*Grade II*	*Grade III*	*Grade IV*	*Grade V*	*Total*
Standard method*						
Grade I	17	0	0	0	0	17
Grade II	0	9	0	0	0	9
Grade III	2	21	20	2	0	45
Grade IV	0	0	0	18	0	18
Grade V	0	0	0	0	8	8
New method†						
Grade I	17	0	0	0	0	17
Grade II	2	26	0	0	0	28
Grade III	0	4	20	2	0	26
Grade IV	0	0	0	18	0	18
Grade V	0	0	0	0	8	8
Fujitani method‡						
Grade I	17	9	0	0	0	26
Grade II	2	17	2	0	0	21
Grade III	0	4	18	15	0	37
Grade IV	0	0	0	5	0	5
Grade V	0	0	0	0	8	8
ICA/CCA ratio method§						
Grade II	12	11	2	0	0	25
Grade III	7	19	16	2	0	44
Grade IV	0	0	2	18	0	20
Grade V	0	0	0	0	8	8

*Kappa = 0.676; 95% CI = 0.571 to 0.782; kappa ± SD = 0.676 ± 0.054.
†Kappa = 0.894; 95% CI = 0.823 to 0.964; kappa ± SD = 0.894 ± 0.036.
‡Kappa = 0.579; 95% CI = 0.464 to 0.695; kappa ± SD = 0.579 ± 0.059.
§Kappa = 0.546; 95% CI = 0.341 to 0.751; kappa ± SD = 0.546 ± 0.105.
Kappa statistics for the new method are significantly higher ($p < 0.001$) than those for any other method.

Table III, E. Effect of grade V contralateral stenosis on duplex grades of ipsilateral stenosis

Ipsilateral stenosis duplex grades	*Angiogram grades*					
	Grade I	*Grade II*	*Grade III*	*Grade IV*	*Grade V*	*Total*
Standard method*						
Grade I	3	0	0	0	0	3
Grade II	0	2	0	0	0	2
Grade III	0	10	14	0	0	24
Grade IV	0	0	0	8	0	8
Grade V	0	0	0	0	2	2
New method†						
Grade I	3	0	0	0	0	3
Grade II	0	12	1	0	0	13
Grade III	0	0	13	0	0	13
Grade IV	0	0	0	8	0	8
Grade V	0	0	0	0	2	2
Fujitani method‡						
Grade I	3	3	0	0	0	6
Grade II	0	9	3	0	0	12
Grade III	0	0	11	7	0	18
Grade IV	0	0	0	1	0	1
Grade V	0	0	0	0	2	2
ICA/CCA ratio method§						
Grade II	2	4	0	0	0	6
Grade III	1	8	13	0	0	22
Grade IV	0	0	1	8	0	9
Grade V	0	0	0	0	2	2

*Kappa = 0.640; 95% CI = 0.457 to 0.823; kappa ± SD = 0.640 ± 0.093.
†Kappa = 0.965; 95% CI = 0.896 to 1.0; kappa ± SD = 0.965 ± 0.035.
‡Kappa = 0.537; 95% CI = 0.339 to 0.735; kappa ± SD = 0.537 ± 0.101.
§Kappa = 0.628; 95% CI = 0.308 to 0.947; kappa ± SD = 0.628 ± 0.163.
Kappa statistics for the new method are significantly higher ($p < 0.001$) than those for any other method.

sensitivity was 100%, the specificity was 92%, the positive predictive value was 92%, and the overall accuracy was 96%. A similar poor specificity, lower positive predictive value, and overall accuracy were noted when the ICA/CCA ratio method was used. The Fujitani method had comparable results to the new method. The overall accuracy of the new method was statistically superior to that of the standard and ICA/CCA ratio methods ($p < 0.001$).

Effect of contralateral total occlusion

Again, as noted in Table VI, the sensitivity in predicting ≥50% ipsilateral stenosis in this group of patients with the standard method was 100%, with a specificity of only 33%, a positive predictive value of 71%, and an overall accuracy of 74%. In contrast, the new method had a sensitivity of 96%, a specificity of 100%, a positive predictive value of 100%, and an overall accuracy of 97%. A similar poor specificity, a lower positive predictive value, and a lower overall accuracy were noted when the ICA/CCA ratio methods were used. Again, the Fujitani method was comparable to the new method in all of these parameters.

The overall accuracy of the new method was statistically superior to that of the standard and ICA/CCA ratio methods ($p < 0.001$). As noted in Tables V and VI, whether the degree of contralateral stenosis was 80% to 99% or total occlusion, no difference was seen in the accuracy of the four methods that were used.

Effect of contralateral tight stenosis (80% to 99%) or total occlusion on the diagnosis of equal to or >80% ipsilateral stenosis: Effect of 80% to 99% contralateral stenosis

The sensitivity in predicting ≥80% ipsilateral stenosis with the standard and new methods was 93%, with a specificity of 100%, a positive predictive value of 100%, a negative predictive value of 97%, and an overall accuracy of 98%. Similarly, a sensitivity of 93%, a specificity of 97%, a positive predictive value of 93%, a negative predictive value of 97%, and an overall accuracy of 96% were obtained with the ICA/CCA ratio method. These results were in contrast to those of the Fujitani method, which had a sensitivity of only 46%, a specificity of 100%, a positive predictive value of 100%, a negative predictive value of 82%, and an overall accuracy of 85%. The overall accuracy of the standard, new, and

Table IV. Comparison of duplex methods versus arteriography for sensitivity/specificity in diagnosis of ≥ 50% ipsilateral stenosis in patients with arteries of 50% to < 80% stenosis on contralateral side

	Carotid arteriogram							
	< 50% Stenosis (%)	*≥ 50% Stenosis (%)*	*Total*	*Sensitivity (%)*	*Specificity (%)*	*PPV (%)*	*NPV (%)*	*Overall accuracy (%)*
Standard method								
< 50% Stenosis	24 (100)	0	24	100	56	78	100	83
≥ 50% Stenosis	19 (22)	68 (78)	87					
New method								
< 50% Stenosis	42 (95)	2 (5)	44	97	98	99	95	97
≥ 50% Stenosis	1 (1)	66 (99)	67					
Fujitani method								
< 50% Stenosis	42 (91)	4 (9)	46	94	98	98	91	96
≥ 50% Stenosis	1 (1)	64 (99)	65					
ICA/CCA ratio method								
< 50% Stenosis	19 (86)	3 (14)	22	96	44	73	86	76
≥ 50% Stenosis	24 (27)	65 (73)	89					
Total	43	68	111					

New method versus standard method, $p < 0.001$ (Z statistics for proportion).
New method versus Fujitani method, $p > 0.05$ (Z statistics for proportion).
New method versus ICA/CCA ratio method, $p < 0.001$ (Z statistics for proportion).
PPV, Positive predictive value; *NPV*, negative predictive value.

Table V. Comparison of duplex methods versus arteriography for sensitivity/specificity in diagnosis of ≥ 50% ipsilateral stenosis in patients with arteries with 80% to 99% stenosis of the contralateral side

	Carotid arteriogram							
	< 50% Stenosis (%)	*≥ 50% Stenosis (%)*	*Total*	*Sensitivity (%)*	*Specificity (%)*	*PPV (%)*	*NPV (%)*	*Overall accuracy (%)*
Standard method								
< 50% Stenosis	26 (100)	0	26	100	53	68	100	76
≥ 50% Stenosis	23 (32)	48 (68)	71					
New method								
< 50% Stenosis	45 (100)	0	45	100	92	92	100	96
≥ 50% Stenosis	4 (8)	48 (92)	52					
Fujitani method								
< 50% Stenosis	45 (96)	2 (4)	47	96	92	92	96	94
≥ 50% Stenosis	4 (8)	46 (92)	50					
ICA/CCA ratio method								
< 50% Stenosis	23 (92)	2 (8)	25	96	47	64	92	71
≥ 50% Stenosis	26 (36)	46 (64)	72					

New method versus standard method, $p < 0.001$ (Z statistics for proportion).
New method versus Fujitani method, not significant (Z statistics for proportion).
New method versus ICA/CCA ratio method, $p < 0.001$ (Z statistics for proportion).
PPV, Positive predictive value; *NPV*, negative predictive value.

ICA/CCA ratio methods was superior to that of the Fujitani method ($p < 0.001$). The poor sensitivity of the Fujitani method can be easily explained by the requisite of an end-diastolic frequency of the internal carotid artery of > 5 kHz for the diagnosis of grade IV stenosis instead of > 4.5 kHz, as in the other methods (see Table I).

Effect of contralateral total occlusion

The sensitivity, specificity, positive and negative predictive values, and overall accuracy in predicting ≥ 80% ipsilateral stenosis with the standard and new methods were 100%. A similar sensitivity and negative predictive value of 100%, a positive predictive value of 91%, and a specificity and overall accuracy of

Table VI. Comparison of duplex methods versus arteriography for sensitivity/specificity in diagnosis of ≥50% ipsilateral stenosis in patients with total occlusion on contralateral side

	Carotid arteriogram							
	<50% Stenosis (%)	*≥50% Stenosis (%)*	*Total*	*Sensitivity (%)*	*Specificity (%)*	*PPV (%)*	*NPV (%)*	*Overall accuracy (%)*
Standard method								
<50% Stenosis	5 (100)	0	5	100	33	71	100	74
≥50% Stenosis	10 (29)	24 (71)	34					
New method								
<50% Stenosis	15 (94)	1 (6)	16	96	100	100	94	97
≥50% Stenosis	0	23 (100)	23					
Fujitani method								
<50% Stenosis	15 (83)	3 (17)	18	88	100	100	83	92
≥50% Stenosis	0	21 (100)	21					
ICA/CCA ratio method								
<50% Stenosis	6 (100)	0	6	100	40	73	100	77
≥50% Stenosis	9 (27)	24 (73)	33					

New method versus standard method, $p < 0.01$ (Z statistics for proportion).
New method versus Fujitani method, $p = 0.15$ (Z statistics for proportion).
New method versus ICA/CCA ratio method, $p < 0.01$ (Z statistics for proportion).
PPV, Positive predictive value; *NPV*, negative predictive value.

97% were obtained with the ICA/CCA ratio method. In contrast, a poor sensitivity (30%), a lower negative predictive value (81%), and an overall accuracy of 82% with a specificity and positive predictive value of 100% were obtained with the Fujitani method. The overall accuracy of the standard, new, and ICA/CCA ratio methods was superior to that of the Fujitani method ($p < 0.001$).

DISCUSSION

Although several different criteria have been proposed for the interpretation of carotid duplex studies, we chose to compare our new modified criteria to the standard criteria proposed by Zierler and Strandness (University of Washington),[6] the Fujitani et al. criteria,[5] and the ICA/CCA ratio criteria.[7] The standard criteria were chosen because of their widespread use and their well-documented consistency. The ICA/CCA ratio criteria were chosen because of their widespread use in the radiology community. Finally, the Fujitani criteria were chosen for comparison because these criteria were designed for use in the presence of contralateral total carotid occlusion.

Our results allowed comparison of these criteria in a variety of circumstances. As Table II demonstrates, both the standard and ICA/CCA ratio criteria tended to overestimate the ipsilateral disease severity. The effect was most impressive at the grade III level, in which both the standard and ICA/CCA ratio criteria overestimated the degree of stenosis in 30% of cases.

When the Fujitani criteria were evaluated, we found a tendency to underestimate the severity of the ipsilateral stenosis. This effect once again became most evident and was most impressive at the grade III level by the duplex technique, in which 38% of the arteries were found to have grade IV stenosis by arteriography. One possibility for this finding is that the Fujitani criteria were applied to all patients in our study rather than just those with total unilateral occlusion as described in their study.

The new proposed criteria fared very well in the analysis, with only 3% overall overestimation of the disease and 3% overall underestimation of the disease. The overall exact correlation between duplex and arteriographic grading was 94% and was superior to the other criteria in each case ($p < 0.001$).

The new criteria yielded sensitivity, specificity, positive and negative predictive values, and overall accuracy values superior to those of the other three criteria in predicting ≥50% ipsilateral stenosis, when all patients with 0% to 100% contralateral stenosis were included ($p < 0.001$ in each case). When divided into 50% to <80% contralateral stenosis and 80% to 99% contralateral stenosis or total occlusion, the new criteria proved once again to be superior to the standard and ICA/CCA ratio criteria ($p < 0.001$). The differences between the new criteria and Fujitani criteria in these patients did not reach statistical significance. This finding is not surprising, because the Fujitani criteria were developed from a study in which the contralateral artery was totally occluded and were designed to be used in such cases rather than to be applied to all vessels studied, as they were in this series.

Some clinicians believe that the most important clinical issue is accuracy in detecting stenoses of greater than or less than 80%, contralateral to a tight stenosis or occlusion. The standard method results were very comparable to the new method and somewhat comparable to the ICA/CCA ratio method in all parameters examined, including the overall accuracy. This finding is not surprising, because both the standard and new methods require an end-diastolic frequency of the internal carotid artery of >4.5 kHz for the diagnosis of ≥80% stenosis. However, the Fujitani method had a poorer sensitivity and an overall accuracy of only 85% in contrast to an overall accuracy of 98% for the new and standard methods in this group of patients (80% to 99% contralateral stenosis). This finding can be explained by the requirement of an end-diastolic frequency of the internal carotid artery of > 5 kHz for the diagnosis of ≥80% stenosis for the Fujitani method. Similar observations were noted in patients with a total contralateral occlusion.

Our results are comparable with data previously reported by others.[1-5] However, Fischer and Alexander[8] reported that contralateral stenosis had no effect on the Doppler frequency of the ipsilateral side. Hayes et al.,[3] in a multicenter study with a continuous-wave 5 Mhz Doppler probe, concluded that the mean peak frequency of the internal carotid signals for all grades of stenoses was directly related to the extent of the contralateral stenosis and that that effect was most evident when the contralateral stenosis was occluded. They concluded that 43% of the false-positive errors were attributed to contralateral carotid artery occlusion. A receiver-operating characteristic curve analysis of their data suggests that accuracy in classifying stenoses into greater or lesser than 40% diameter reduction could be improved by increasing the peak frequency criteria from 5500 Hz to 8500 Hz in the presence of contralateral carotid artery occlusion.

Many sources of error are inherent in the interpretation of the internal carotid frequency spectrum, some of which include erroneous assignment of an angle of incidence that is wider than the actual angle of incidence, a tortuous carotid artery, increase in flow velocity in the collateral circulation including the vertebrobasilar system, and the presence of severe contralateral carotid artery disease. Accurate visualization of the vessel, careful positioning of the pulsed-wave Doppler sample volume of appropriate size in the center of the flow stream, and attention to recording the Doppler frequency signal at a beam angle of 60 degrees are very important components of the duplex examination.[4] In patients in whom the contralateral carotid artery is known to be significantly diseased or occluded, the findings from the ipsilateral carotid artery should be interpreted cautiously, particularly for laboratories using the standard criteria. Finding an increased frequency or velocity with little spectral broadening should alert the examiner to the possibility of overestimating the degree of stenosis. Correlation with the B-mode imaging is significantly important in these circumstances.

We believe that these data further illustrate the clinical implications of contralateral carotid stenosis and its effect on duplex accuracy in predicting ipsilateral disease. The proposed new criteria proved superior to the standard and ICA/CCA ratio criteria in all areas studied and superior to the Fujitani criteria in terms of overall correlation of duplex interpretation to the arteriographic findings. In addition, we believe that the restricted population for which the Fujitani criteria were designed makes the use of the new modified criteria even more versatile and attractive, because it was shown to be highly accurate with any degree of contralateral stenosis. However, we acknowledge the need for further study of these criteria before their widespread application.

We thank J. Zhang, PhD, biostatistician.

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DISCUSSION

Dr. Joseph M. Giordano (Washington, D.C.). Dr. AbuRahma and his associates should be congratulated for a fine effort. They have refined parameters to diagnose more accurately carotid artery stenosis. They have shown that slight changes in the standard criteria allow for a more accurate diagnosis of ipsilateral stenosis when there is a contralateral occlusion or severe stenosis. This is important. Both the NASCET and the ACAS study use percent stenosis of carotid artery as an indication for surgery. Therefore anything that increases accuracy in diagnosing stenosis is an important contribution.

The article says little about the mechanism that influences the hemodynamics of an ipsilateral stenosis if the contralateral carotid is stenotic or occluded. The authors suggest that the blood flow increases in the ipsilateral carotid artery to compensate for the tight stenosis on the contralateral side. We all know that increasing flow across a fixed stenosis changes the hemodynamic parameters and, in fact, increases the pressure drop across that area. I cannot help but wonder whether other causes of increased flow across the carotid artery such as an increase in cardiac output change the hemodynamic parameters and therefore may change the threshold for diagnosing a carotid stenosis.

This whole approach, however, concerns me. Both the NASCET and the ACAS studies used very precise angiographic measurements of carotid stenosis that dictate a clinical course. We are now considering duplex scan, a far less precise study, to determine the degree of carotid stenosis as an initial approach before we order the more precise angiogram. Will the duplex scan, whose interpretation varies according to the standard and even according to the laboratory, deprive patients of the more definitive angiogram?

Is there any scientific proof that a contralateral stenosis or occlusion would cause increased ipsilateral carotid flow? And as a corollary to that, do you know any other entities that would result in increased carotid arterial flow that may have an impact on diagnosing carotid artery stenosis?

No doubt, some of the patients with contralateral stenosis underwent a carotid endarterectomy on the contralateral side. If this did occur, did it have an impact on the diagnosis of ipsilateral stenosis? In other words, did the criteria for diagnosis of stenosis change again to the usual standard with the contralateral carotid now normal?

And, finally, what is the practical significance of the study? Most of the improvement was in the grade 3 stenosis. For patients with symptoms are you going to change your indications for arteriogram on the basis of a duplex scan? For asymptomatic lesion, if a duplex scan shows a narrowing, should we not get an arteriogram if a stenosis is in the 50% to 79% range instead of in the 80% to 90% range?

Dr. AbuRahma (Charleston, W.Va.) There are many sources of error inherent in the interpretation of the internal carotid frequency spectrum, some of which include erroneous assignment of an angle of incidence that is wider than the actual angle of incidence, a tortuous carotid artery, an increase in the flow velocity in the collateral circulation including the vertebrobasilar system, and the presence of severe contralateral carotid artery disease. Accurate visualization of the artery, careful positioning of the pulsed-wave Doppler sample volume of appropriate size in the center of the flow stream, and attention to recording the Doppler frequency signal at a beam angle of 60 degrees are very important. Finding an increased frequency or velocity with little spectral broadening should alert the examiner to the possibility of overestimating the degree of stenosis. Correlation with the B-mode imaging is significantly important in these circumstances.

In regards to your comment regarding this protocol, we believe that what we are proposing is very practical and that this protocol should be applied before deciding to obtain an arteriogram before carotid endarterectomy. Perhaps for symptomatic lesions it might not be that critical, because I personally operate on patients with ≥50% stenosis if they have the classical transient ischemic attack symptoms rather than waiting for a 70% lesion. However, this becomes more critical when operating on patients with asymptomatic stenosis, particularly because the ACAS study is advocating the benefit of endarterectomy for patients with ≥60% stenosis. Overestimating the disease in these cases becomes more critical in an institution like ours, where the stroke rate after cerebral arteriography can reach up to 1%.

Dr. Ricotta (Buffalo, N.Y.) We have looked at that, not in an organized way, but I can tell you in our laboratory when we have people with bilateral stenoses, I always do a duplex after I have fixed one, before I go ahead to fix the second one, and those velocities come down significantly. I think it is important if you are going to be pursuing endarterectomy without angiography that you either repeat your studies in between times, you develop some sort of criteria like this, or you decide that everybody who has bilateral disease is going to get an angiogram.

I just had somebody 3 weeks ago, bilateral 80% stenoses or greater by duplex; fortunately, we picked the right side. The patient refused an angiogram, he had had a dye reaction before, we picked the right side, restudied him afterwards, and he is in a 50% category on the contralateral side. So it is a real problem. There can be real problems if you are not going to do angiography in people with bilateral disease.

Dr. AbuRahma (Charleston, W.Va.) I agree.

ERRATUM

An error has been brought to the Editors' attention in "Norman Freeman: The 'first' American specialist in vascular surgery" by John E. Connolly, J VASC SURG 1995;22:188-94. On page 192, Fig. 4 was placed over the legend for Fig. 5, and Fig. 5 was placed over the legend for Fig. 4.